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PROCEEDINGS OF THE FIFTH SYMPOSIUM - PACIFIC NORTHWEST ON SILTATION - ITS SOURCES AND EFFECTS ON THE AQUATIC ENVIRONMENT, MARCH 23-24, 1959

Public Health Service
Portland, Oregon

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FIFTH SYMPOSIUM - PACIFIC NORTHWEST

ON

SILTATION - ITS SOURCES AND EFFECTS

ON THE AQUATIC ENVIRONMENT

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Portland, Oregon

FOREWORD

Two years ago the Public Health Service initiated a project in the Pacific Northwest for the purpose of testing an idea for a program by which to better reach and serve those engaged in water pollution research in this area. This project was given the title "Technical and Research Consultation Project." Its major objectives are to encourage, guide, coordinate and develop research in this field.

A series of symposiums is one of the devices used to accomplish these objectives. To date five symposiums including the one herein reported have been held. The subjects covered are:

First, Research on Water Pollution in the Northwest.
Second, Financing Research Projects.
Third, The Sphaerotilus (Slime) Problem.
Fourth, Short-Term Bioassay.
Fifth, Siltation - Its Sources and Effects on Aquatic Life.

This fifth symposium was arranged and conducted by Edward F. Eldridge, Physical Sciences Administrator, and John N. Wilson, Biologist. It was divided into two parts. The first consisted of a field trip to observe the use of sampling equipment. The second was a series of discussions of selected subjects.

Thirty-three persons attended the field demonstration and fifty-eight the discussions. An attendance list is attached as an appendix to these proceedings.

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March 23-24, 1959

Assembled by
Edward F. Eldridge
John N. Wilson

Opening Remarks - E. F. Eldridge

Two years ago I joined the Public Health Service on a project which we chose to call "Technical and Research Consultation Project, Pacific Northwest." One of the major objectives of this project is to stimulate, encourage, guide, advise, coordinate, and develop research on problems relating to water pollution in this area. This has been somewhat of an experiment on the part of Public Health Service to find better ways to serve you who are conducting research or technical studies on actual field problems. Symposiums, of which this is the fifth, have been initiated as one of the methods by which we hope to stimulate interest in various problems and to bring groups together for an exchange of information.

These symposiums are informal - they are not conferences in which papers are read. We have selected leaders who will make brief statements of the specific items we are to consider. The subject will then be open for general discussion. Everyone is invited to speak his thoughts.

As you know, the subject of this symposium is "Siltation - Its Sources and Effects on the Aquatic Environment." We have limited it to the aquatic environment, although there are many other phases of the problem which we might discuss.

Yesterday thirty-three persons took part in a field demonstration of equipment which took place in the Sandy River near Troutdale about eighteen miles east of Portland. The following is a list of the equipment demonstrated.

A. For the measurement of physical and chemical factors in salmon and steelhead redds.
   1. Permeameter for the measurement of permeability.
   2. Standpipes for determination of dissolved oxygen, carbon dioxide, etc., in spawning gravel.
   3. Gravel sampler for determination of fines.

B. For the collection of fish-food organisms.
   1. Surber square-foot bottom sampler.
   2. Reconnaissance screen.
   3. Quantitative screen dipper.

Purpose and Scope of the Symposium - John N. Wilson

There has been increasing emphasis in recent years on cooperative programs in the realm of water resources. Witness the large number of alphabetized interagency groups: The Arkansas White Red Interagency Committee, AWRBIAC, the Missouri Basin Interagency Committee, MBIAC, and of course our own Columbia Basin Interagency Committee, CBIAC. Most of these groups have been assembled with the common goal of wise development and use of our water resources.

Those in attendance at meetings of such groups are impressed by the fact that most of the subjects discussed relate to engineering aspects of flood control, pool levels, firm power, runoff, snow surveys, and the like. In the Pacific Northwest, the urgency of problems relating to the anadromous fish runs has compelled an acceleration of research applied to fish passage facilities and a multitude of factors in the preservation of this important resource.

Among these factors is a growing awareness of the need for bringing water quality control into the whole matter of interagency thinking and planning for fisheries and for water supplies for our expanding population and industry.

Closely tied to water quality control is the significance of aquatic ecology - the aquatic environment. Streams and lakes are comparable in many ways with living organisms. We are here dealing, not only with the cold facts of the amount and distribution of water, but also with complex biotic interactions that take place under the surface of these waters - interactions that are affected in one way or another by all accepted legitimate uses of our waters.

Let me explain by citing a striking illustration of where radical misuse of a water course has impaired other uses. I refer to the siltation problem in the lower ninety miles of the Bear River, southeastern Idaho - northern Utah.

Some thirty years ago a fourteen-year-old boy leaped across a grass covered, bushy gully in the watershed of Five Mile Creek, tributary to Bear River near Preston, Idaho. Since that day some thirty years ago, increased irrigation and agriculture in this erodable sandy soil has opened the gully and washed an estimated ten million tons of sand of 0.1 - 0.3 millimeter size into the Bear River. Where once a boy leaped from rim to rim, the distance across the chasm is presently more than five hundred feet with a depth exceeding one-hundred fifty feet.

The results of this heavy load of settleable material on the Bear River have been several. The depth of deposition over the entire ninety mile reach varies from six to eight feet, filling pools and burying riffles which once constituted a favorable environment for one of the finest trout populations in the intermountain area. Now only a few carp can survive.

I have personally had the opportunity to work with the two states

on the interstate pollution problem which has been superimposed upon that of siltation. The over-all problem has been rendered complex by the fact that the capacity for natural purification which is normally available in rivers has been reduced to a very low level. The stream is a virtual biological desert.

By way of contrast, I'd like to cite the example of a different type of stream in the Middle West where siltation has not been a major problem. Instead, a heavy load of industrial and municipal waste has been the problem. Wastes were discharging into a turbulent reach of this river over a rocky bottom. Because there was little siltation, there was minimum interference with growth of organisms which are responsible for natural purification. The resulting rapid rate of assimilation of these wastes caused the investigating engineers to do a "double take." Most of them had never witnessed such a remarkable example of stream self-purification.

I cite this because it points up the need for better understanding of all factors in the aquatic environment. Such an understanding is essential to interpretations of all aspects of water quality. Investigators armed with knowledge of environmental factors in waters can interpret the reasons for the natural purification cited in the instance of the midwestern stream versus the extremely slow rate in Bear River. This is basic, but often overlooked.

For these reasons, we are devoting the first portion of this symposium to a consideration of the aquatic environment. We shall start with a discussion of the effects of siltation and turbidity upon photosynthesis in aquatic plants, primary productivity, if you will, followed by the next principal group in the food chain, the fish food organisms and culminating in the fish themselves.

The discussions this afternoon will deal primarily with watershed management and water uses. We will start with the watershed for, as you all know, water quality control starts with the raindrop falling on the land. We will then move down along watercourses and include other water uses which bear on the problem of siltation.

Turbidity, Sedimentation and Photosynthesis - Dr. Harry K. Phinney

If I took the simple approach to this problem, the usually accepted approach that generalizations and approximations are sufficiently accurate for biological work, this could be a brief, most understandable and enjoyable report. For the sake of contrast, I would like to state the generalizations that relate turbidity and sedimentation to the photosynthetic process and then attempt to explore the ramifications of these relationships.

Statement #1. Light passing through a turbid medium suffers a reduction in intensity, in all wave lengths, that is approximately proportional to the concentration of suspensoids. The rate of the photosynthetic process is approximately proportional to the amount of available light. Ergo: As turbidity increases the rate of photosynthesis decreases.

Statement #2. The physical effect of a layer of sediment is that of a mechanical barrier to the mass movement of the ambient medium over the surfaces lying under the sediment layer. Gas exchange between multicellular organisms or aggregates of unicellular organisms so buried cannot be accomplished solely by diffusion with sufficient rapidity to maintain life processes in most aerobic organisms. Ergo: Sedimentation will result in the serious reduction in the photosynthetic rate of attached aquatic plant communities. If the reduction is to a level below the compensation point, oxygen to carbon dioxide, very marked changes will occur in the population.

Sounds scientific, doesn't it? It's scientific enough to warrant using in educational talks to service clubs. I might even use it in a lecture to an elementary course in aquatic biology. The thing that scares me is that 99.9% of the so-called research in the area of turbidity and sedimentation problems today results in data that allow for the most part inaccurate conclusions concerning these relationships. If this continues I can guarantee that similar symposia in 1969, 1979, and 1989 will come to the same conclusions as the one today.

The problem to be dealt with is primarily a physical relationship. However, if biologists do not make use of the means of obtaining exact information that are available, we are going to continue to talk in scientific half-truths and generalizations which we cannot use to make well-founded predictions in special cases where such application of knowledge would serve a practical purpose. I have been involved in so much descriptive research where we can tell you what happened and in a general sort of way why it happened, but have been able to use this experience only to formulate "educated guesses" when next I'm called on for an opinion concerning a new problem situation.

"The rate of a simple homogeneous reaction usually is a <u>function</u> of <u>all</u> the relevant factors, e.g. the concentration of all reactants, temperature, and in photochemical processes, light intensity. The

bottleneck stage of photosynthesis may be the supply of light energy, the supply of reactant (CO_2) or the removal of reaction product." Turbidity and sedimentation may affect all of these factors, in some cases even temperature is affected by turbidity.

First, I shall take up the relationship of turbidity to light and photosynthesis. The measurement of the effect of light intensity on the photosynthetic process was first studied by the Russian botanist Volkov in 1866. He counted the oxygen bubbles evolved by submerged aquatic plants placed at different distances from a sun-illuminated, frosted glass window. He reported the rate of gas evolution to be proportional to the intensity of illumination. It was later established that there was a plateau that appeared in curves in which the rate of photosynthesis was plotted against the intensity of incident light. This leveling off of the curve has been called the effect of light saturation and usually occurs at about the intensity of full sunlight (5-6000 fc of 60,000 lux). Beyond the intensity that brings light saturation comes a zone of light inhibition.

It was long assumed that these curves exemplified minimal, optimal and maximal quantities despite the fact that Sachs had already enunciated what was first known as the law of the minimum and more recently rather universally accepted as the limiting factor concept. This whole area of thought was in controversy up to twenty-five years ago, and even now not all objections have been resolved. Experiments with carefully treated plant materials show a simple, direct and reversible response of the rate of photosynthesis to at least two external factors: light intensity and concentration of CO_2 (and within certain narrow limits, also to changes in temperature).

The light saturation levels have been determined for a number of aquatic plants; both algae and flowering plants. Unfortunately, much of the data cannot be directly compared because of a lack of control of temperature or CO_2 concentration. Light values required to bring the photosynthetic rate to ½ that of light saturation have been reported to vary from 0.3 - 20 klux for a variety of species of aquatic plants.

As pointed out by Rabinowitz, the light curves may present a strongly distorted picture of the intrinsic relationship between the rate of light absorption and the yield of photosynthesis, because a considerable gradient of light intensity between the light exposed and the shaded chlorophyll molecules. Even within a single chloroplast the rate of light absorption may decrease by a factor of five or ten from the light exposed to the shaded side; or in the case of diffuse illumination, from the surface to the center of the chloroplast.

In suspensions containing millions of cells the heterogeneous nature of light absorption is further enhanced by the mutual shading of the numerous chloroplasts. Consequently, the light curves of different specimens of one organism, even if they all have the same content of all the relevant pigments and catalysts and are investigated under the same external conditions, may nevertheless differ in

shape, depending on optical density (i.e. the number of cells/cm^2 in an algal suspension).

Let us consider, as the simplest example, two suspensions of identical cells - one optically thin (e.g. transmitting 80% of incident light). There is no reason (aside from production of self-inhibiting metabolic products) why these suspensions should differ in the maximum yield per chlorophyll molecule in strong light. However, the transition from the linearly ascending part to the horizontal part of the light curves will be sharper in the optically thin system (where saturation occurs more or less simultaneously in all cells), and more gradual in the optically dense system (where saturation sets in at the surface of the vessel and spreads inward with increasing intensity of illumination).

Averaging cannot be quite correct because the cells are not actually exposed to the "average" light intensity, but some are illuminated with stronger, and some with weaker light. This would not matter if the yield were proportional to intensity; but if the yield declines with increasing intensity (as it does in the saturation region), the yield that corresponds to a given average intensity will be lower when the spread of actual intensity is wider, i.e. in the more concentrated suspension.

A second complication arises from stirring, which causes cells to come successively into light of different intensities. The effect of this variation is complex. Only if the illumination cycles are much shorter than the periods required for completion of all dark process of photosynthesis can one expect the cells to work, in alternating light and dark, with the same efficiency.

Just consider the additional complications introduced by the turbid medium: (1) reduction in total light intensity, (2) changes from direct to diffuse illumination, (3) effect of optical density on illumination of individual cells, etc. If we correct the gas ratio (CO_2/O_2) for O_2 consumption in cellular respiration we find there is no minimum light intensity for the photosynthetic process. However, there is a point (compensation point) at which the photosynthetic activity becomes apparent by release of O_2 that is produced above the respiratory requirement of the cell. This then becomes a handy marker for the metabolic balance. The compensation points have been determined experimentally for a number of species and the light intensities reported vary from 2-1000 lux. Surprisingly enough some of the plants requiring the highest intensities were green algae.

Again the experimentally determined data are not comparable because such things as temperature and CO_2 concentration were not held to a standard. In any case, such data would be useful only as a starting point for investigations of natural populations under field conditions. So now we arrive at the question of the utility of the compensation point. I have little reason to doubt that all here have long since realized that this datum is the objective of all 24-hour oxygen studies and such things as black bottle experiments. The objective in such studies is to determine the level of photosynthetic activity of the autotrophic element of the

population and whether it exceeds the level of activity of the heterotrophic population. However, I find it disturbing that so few studies have deemed it necessary to attempt to define this relationship specifically. It seems obviously pointless to determine B.O.D. and ignore oxygen production as a dynamic process. There should be no study that is deemed sufficiently important to require a determination of B.O.D. and not concurrently study the dynamics of oxygen production under standard conditions. I will go further and say that one without the other results in ambiguous data. To relate this physical data to biological data, laboriously assembled as it must be, is a fraud, for in the end it cannot be determined whether the physical factors are the cause or the effect. You may think that yours is a practical problem and you are not interested in such an academic approach. But after all nothing could be more academic, more divorced from reality than B.O.D. data when all by itself it is interpreted as an index of the metabolic well-being of the habitat.

Let us see what kind of relationships with light have been established for photosynthesis in turbid media. And I quote! - First, from Dorsey (1940). "The transmission of light by many coastal and inland waters is subject to wide fluctuations caused by variations in the turbidity and in the plankton. The amount of plankton varies with the season and with weather; and the turbidity with the amount of detritus, sand, and soil whether brought in by streams or surface drainage or stirred up from the bottom. Measurements of the transmission and of the effective absorptivity under such conditions are of no general value, but are of significance with reference to the actual plankton growth at the place and time considered; many such measurements have been made for the purpose of obtaining data for correlating plankton growth with the illumination existing at various depths." Nineteen years ago this was true, today it is true. The only application we can make of this light transmission data is to correlate it with plankton development on a relative basis; in the same habitat by means of successive measurements. We cannot relate this data to other situations except by direct comparisons. All that can be said is "they are the same" or "they are different." I don't care whether these two situations are the same or different (and really neither do you). The only real interest there can be in establishing such a relationship is to be able to say "for this reason they are the same (or different)." Or to be able to predict that a new situation will parallel or differ from another in response to the turbidity because.....Because? Because what? Listen to this -

"The three component analysis of the waters of the Wisconsin lakes indicates that although filtration almost always reduces the color of the water, the suspensoids remaining in settled waters are relatively unselective in their optical effect. Moreover, for low colors (Pt units $\leq$ 20), the variations in absorption due to suspensoids is apparently largely independent of color."

Now this is the profound judgement passed, by one I'm willing to recognize as a genius of our time; on two hundred and twenty printed

pages of data laboriously collected some twenty years earlier by methods that were already 25 years out of date.

The statement is from Hutchinson's "A treatise on limnology" evaluating the information from Juday & Birge and Whitney done in 1938 by essentially the same methods as used by Aufsess and Pietenpol ten to twenty years earlier.

Schuster, in 1903, published a theory of the effect of radiation on the transmission of heat through matter. Here he set forth very clearly the philosophy that every volume element within the medium receives scattered light from every other volume element. This has been called the principle of self-illumination. In 1905 Schuster expressed the principle of self-illumination in terms of two diffused fluxes moving in opposite directions through the material, each contributing back-scattered flux to the other. It only took 33 years for aquatic biologists to get around to trying to find out what this meant as far as effects on illumination in natural waters were concerned. And when they did the procedure used was that of Schuster, although in 1927, eleven years earlier, Silberstein (Phil. Mag. 4:129) had pointed out that when non-radiating turbid media are permiated with light from an external source, the residue of the unscattered beam obeys a different law from the scattered.

By 1942 S. Q. Duntly of M.I.T. had formulated equations that allowed him to pronounce the following facts:

"When radiation falls on a layer of particles having completely random orientation and positions, the total amount of scattering is independent of the angular cone of incidence, for each element of the cone will be scattered like a parallel bundle. Accordingly it is true that the total flux scattered backward and forward is equal to the total of the portions of the diffused flux scattered backward, that is again scattered forward and backward, in a system with random orientation and position of particles. This will not be true in systems where such orientation exists."

"In the interest of generality it must be recognized that the absorption coefficient for incident light need not be the same as that for internal diffused light. Not only is a different path length involved but in a system not possessing completely random orientation and position of particles, a greater portion of the light may traverse the layer without striking a particle in the case of incident light, than in the case of diffused light." And he proceeds to differentiate an equation to describe the internal optical properties of diffusing material. Unfortunately none of Duntly's equations contain correction for wave length differences, all of his work being performed in monochromatic light.

Chandler (1942) in a paper on the biological effects of turbidity and its variations in western Lake Erie says - "turbidity...may influence: (1) composition, size, duration and time of occurrence of phytoplankton

pulses; (2) rate of photosynthesis at various depths; (3) position of the compensation point of higher aquatic plants and phytoplankters; (4) vertical distribution of microcrustacea, and (5) magnitude of the commercial catch of sougers."

Are these statements true? Undeniably they are true. But just what are the turbidity effects? At what level of turbidity will these effects arise? What type of suspended matter, size and orientation is involved? Chandler could not answer these questions from his data nor can I because the turbidity measurements were made by a 30-year old method based on a theory that does not apply.

In 1954, J. Verduin published a paper on phytoplankton and turbidity which translated Chandler's data and that of others to an even less meaningful form and presented it as related to "depths associated with 1% of surface light."

The reports of Schuster (1903) Silberstein (1927) and Duntly (1942) have all shown the fallacy of light transmission measurements, whether estimated in the field by means of a photometer of some sort or approximated in the laboratory with a spectrophotometer. The calculations involved in these procedures count scattering as another type of absorption. As far as the photometer is concerned, whether this uses a photoelectric cell or a direct visual comparison with standards, the methods do not differentiate absorption from scattering. As Dorsey (1940) says; "The fraction of the incident radiation transmitted by a given layer of water depends upon the amount laterally scattered by the water, as well as upon the amount truly absorbed, i.e. converted into another energy form. But the distinction has seldom been observed in reporting experimental data, the entire reduction in intensity being generally described as absorption. May I point out that the use of the platinum cobalt scale for anything other than the crudest survey work is a complete waste of time for the above stated reason even if there was not the other and more serious objection that visual comparison of different colors is a sheer impossibility.

I think that it would be wise to also emphasize another vagary of light in turbid suspensions. As the particles in suspension become more concentrated, more and more of the light emerging from the turbid layer is emitted by the turbid particles. In these cases the suspension itself begins to act as the source of light for the photocell. When a concentration is approximated where the transmitted light is essentially equal to zero, further changes in concentration of scattering particles means only a change in the intensity of the light source.

If there is an interest in relating physical and biological facts concerning populations existing in turbid media, certain critical factors must be considered.

1. What is the metabolic status of the population (the CO_2/O_2 ratio). And this does not mean simply B.O.D.s.

2. What are the light transmitting qualities of the medium.

   (a) Absorption
   (b) Diffuse scattering

   This cannot be simply transmission data nor can it be developed from photometer readings in the field.

3. What are the characteristics of the suspensoids, and the color that is controlling light transmission?

If turbidity and sedimentation are adjudged a prime factor in controlling biological development in a problem situation, nothing less than an all out analysis will prove a waste of time, money and effort in answering the all-important question of why.

Discussion - abstracted -

The statement was made that in studies over oyster beds primary productivity and the effect of turbidity on productivity is measured by three methods, namely:

1. Dark-light bottle tests for photosynthetic oxygen production.

2. Determination of chlorophyll by spectro photometry.

3. The use of the take-up of C^{14}.

The latter is favored mainly because it involves less labor, however, the speaker had not developed completely satisfactory techniques. The bottle test for oxygen production, especially in the presence of organic material, does not exactly duplicate natural conditions of light intensity. Also, the B.O.D. interferes with the measurement of oxygen production in the light bottles.

Dr. Phinney indicated that the C^{14} technique is perfectly acceptable. He stated that it is also possible to make determinations of the effects of turbidity on light transmission under average illumination in the study area and then transfer these conditions to the laboratory, using artificial illumination. This method will approximate the field measurements using C^{14} techniques.

The establishment of the metabolic relationship that exists in the population using the carbon dioxide-oxygen ratio as an index is probably the best single method. This is a difficult method in streams where siltation and turbidity is high. Any technique is difficult under such condtions.

The question was asked, "Is color and turbidity worth measuring?" The answer was yes as they relate to water supplies. In these cases the usual methods are adaptable since water quality standards are based on these methods. These methods may not be applicable to a study of

the aquatic environment and where interest is in productivity in the habitat. These tests do not tell the story as far as light has an effect on the biota.

Reference was made to a technique for separating the effects of color and turbidity in water on light transmission which is fairly simple and shows possibilities. The technique is described in papers by Jullander and Brunse, "Light Absorption Measurements on Turbid Solutions," Acta. Chem. Scand. 4, 870 (1950) and 3, 1309 (1949). The method was discussed as a system to determine the optical properties of turbid waters.

Much of the literature review on this subject occurs, not in the water field, but in the book by Rabinowitch "Photosynthesis and Related Processes," Vol. II, Part II (1956). A very complete bibliography on the subject is contained in this book.

We cannot measure or understand the relationship between the metabolic activity of the aquatic biota and the physical factors of the environment until we are ready to accept the techniques which will allow for the most accurate measurement of those physical factors. We are using techniques which are poor and out of date and yet we wonder why for years and years we accumulate data and the only thing we can do with it is to make the most general statements with low potential in application.

There is a practical demand for measurement and such methods are available in the field of physical chemistry, but are objected to by biologists as being complex and without the budgetary abilities.

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Effects of Siltation on Production of Fish Food Organisms - Don W. Kelley

The subject of the effects of siltation on aquatic organisms is rather new to me. I am a regional or district fisheries biologist and spend almost all of my time doing so-called fisheries management work and this discussion is an accumulation of recent nights and week-ends that I have spent trying to catch up on some of the literature. I am going to really take you through some of the thinking that I have gone through hurriedly.

The first thing I would like to say is that in general I believe that silt in normal quantities in streams ordinarily does not seem to have a direct effect upon fish. Wallace, in 1951, tested 16 species of fish and found no change in the behavior of those fish until turbidity reached 20,000 to 100,000, depending upon the species. He increased turbidities up to 175,000 and 225,000 ppm before any of these species died. I think we have all brought fish into the laboratory and held them in the effluent from gravel plant where turbidities were extremely high and found that they lived there until they starved to death.

The indirect effects of turbidity and siltation, however, are often disastrous. I think all of us have seen too that many cases where the bottoms of streams and rivers are completely covered with silt and where bottom fauna has disappeared. In many cases the bottom fauna are killed directly. They too breathe, in certain cases with gills, and an excess of turbidity or deposition of fine material on the bottom will smother them, just as it would fish, if fish had to live in the bottom. We have had a few cases in California over on the north coast where the silt was so bad that it smothered the fish. Before Dr. Phinney spoke I thought it was pretty obvious that an increase in turbidity of the stream or lake would affect the photosynthesis. I think this is still true, although we may not be able to measure it and that since many of the fish food organisms, be they bottom organisms in a stream or lake, or planktons, are affected by increased turbidity because many of them are browsers and need plant life for food. Anything that affects plant life, particularly microscopic plant life, is going to affect fish food organisms.

There have been a great many statements made about the general change in turbidity, particularly in the Middle West, during the time when the pioneers broke the sod and increased the turbidity of the middle-western streams and caused a tremendous change in the fish population. The Surber sampler was not available at that time, but we might presume that at least part of the effect was due to turbidity and siltation on fish foods.

How important is food? We know that fish need it, but is it the limiting factor? Are there other things that fish need, such as shelter or spawning area that are presently limiting the size of the fish population? If food is not the limiting factor, if there is in fact a surplus of food, perhaps the fish populations are affected in some other way before the decline in the fish food organisms. I think in some cases

food is not the limiting factor. We have been doing some survey work on trout streams in connection with natural erosion and erosion that is caused, or at least accelerated, by mans' activities on the watershed. I believe, however, that in this case perhaps shelter is the limiting factor rather than the food supply. Much of the shelter for these small trout is destroyed.

There has been a general acceptance of the fact that food is a limiting factor in many cases. K. Redway Allen in a very classical report, although not concerned with siltation, determines fairly well that food is a factor that limits the size of the fish population.

It is these situations which occur before you get to the point where the bottom food is smothered out that bother us. When the bottom food is smothered out, such as by a mine discharge or a gravel operation, we can get a clear picture. The problem in this case is purely administrative - problems of law enforcement. But I think we have a much greater problem before we get to that point. The thing that we must try to understand is that there is a vast difference between production of fish food organisms and a standing crop of fish food organisms. H. K. Townes, in working on a reservoir in lower Hudson River area, found that silt reduced the bottom organisms in this reservoir by diluting the organic debris in the bottom so that animals living on the bottom had a poor food supply. Allen in his study found also that the standing crop of food organisms was much less than the production. Richardson, in 1921, in working on the Illinois River, did a vast amount of bottom sampling. He calculated that the standing crop of fish food organisms on the bottom will only last the standing crop of fish, a few months in some cases if the standing crops of organisms were stabilized and if production ceased. The fish would only last a few months until they starved to death. He calculated this for a number of different places in the Illinois River. All these things I believe point out that you can't measure the effects upon standing crop and have to measure the dynamic effects upon production.

I would like to know how much sand or silt is permissible in the bottom of the stream or lake. I want to know how turbid the water can be and for how long. I want to know too what happens to the silt when it comes off the hills up in the sierras and does its damage there. A year or two later it is washed out into the foothills doing its damage there. Where does it go from there? What happens to the tons and tons of mining silt that were at one time in California and were washed down by hydraulic mining? Is it doing some damage now to the ocean or to the delta? I think these are questions which we must answer. I think that the engineers can help us and I have just recently realized that they have been working on silt and siltation for a long time.

I want to know too what sort of research we need on this subject. Fisheries research in the last two years, at least in this country, has tended to become more practical than basic. We have, to a great extent, neglected the habitat.

Discussion - abstracted -

The question was asked, "Are there any experiences which would indicate that turbidity was advantageous?" An example was cited wherein the greatest population occurred in waters of medium turbidity. The production of plankton was inhibited in the more turbid waters by the depression of light and in clear water by the low concentration of mineral nutrients. Turbidity carries absorbed minerals which support growth if not sufficiently high to limit light.

Important to know the type of turbidity or silt. There are cases where the silt carries high concentrations of lead, copper, and other toxic substances.

Other than the increase in mineral nutrients, increase in turbidity is not beneficial. Reference was made to a paper by Ward written about 20 years ago which is controversial, due to the use of trout as an experimental animal. Since trout are extremely difficult to raise in aquaria, they destroyed themselves in clear water by their own frantic activities. In turbid water they were more quiet since they were not disturbed by outside activities.

It was pointed out that the contribution of the mining industries to the total silt load is about 0.4 percent. Suggestion made that efforts be placed on correcting the larger contribution and the mining industry would be cooperative regarding their contribution. It was pointed out that it was a matter of timing and duration. It seems inevitable that the conditions resulting from man's activities will continue to encroach on the fishery, but the responsibility lies in slowing down this encroachment.

The question of how much is tolerable or what standards of turbidity should be used was discussed. It was admitted that the biologist did not know, but that it would vary widely with conditions. This means that efforts should be directed toward doing what can be done to reduce silt loads. Decisions should be made on the basis of the best knowledge available and in the meantime basic data should be collected. Activities on streams which influence the silt load do not necessarily need to be detrimental. Dams and other impoundments may actually improve fish production by settling out the silt if given the proper study.

Effects of Siltation on Success of Fish Spawning - W. P. Wickett

Our general topic is the sources and effects of siltation. The ultimate aim is to specify undesirable effects and devise means of alleviating and improving existing conditions. We can recognize some general relationships between siltation and spawning success and note a few specific values of survival related to the presence or absence of fine particles. These help our general understanding but are of little use for drawing up an action program. Such a program requires particular values of dependent and independent variables.

First, we should specify what we mean by silt. There are various standard systems of grain identification. If it has not already been done, we should adopt some one system. Appendix B16 of "Low Dams" (1938), a United States Government Printing Office publication, gives a basis for discussion. Silt is generally considered to represent particles in the 0.02 to 0.002 mm range. For the purposes of this discussion all particles below 2 mm, that is coarse to medium sand, are of concern.

I intend to deal only with salmonids in this introduction to the discussion. Other fish eggs, such as bass, are affected by silt. California has long been concerned with the effects of silt in salmon streams. Krogius and Krokhin (1) note that silting has affected the Kamchatka River sockeye since 1930, when extensive forest cutting started. In a 1954 paper (3), I stated that "surface silt of itself did not seem to be lethal, but in certain circumstances it would appear that the circulation of water is so greatly reduced that there is insufficient oxygen for the survival of living eggs or for the disintegration of dead eggs in the gravel."

In addition to losses in the egg stages, a heavy loss of alevins occurred in the spring of 1957 (5) at Jones Creek due to nearly a foot of sand covering parts of the spawning bed. Redd sampling indicated 80% survival to hatching but only 10% of the eggs became migrants. There was 40% survival during two previous years and the subsequent year when the fines were removed.

Some other observations of a more detailed nature can be cited, such as:

1. Under test, the permeability of a large mass of chum salmon eggs was found to be 50,000 cm/hr. The water used was filtered through glass wool, but after a month the permeability was reduced to 25,000 cm/hr apparently due to the fine particles of silt which could be seen on the eggs. In this particular case, the water velocity was 1000 cm/hr, so that survival was nearly 100%.

2. Fine sand washed over the Nile Creek controlled-flow channel reduced the apparent velocity 10 inches below the surface by half (2).

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3. Williams Creek sockeye eggs had a survival rate of 7.5% under silted conditions. In the two years following flushing to remove silt, the survival was 17.2% and 16.5% (3).

4. Alderdice, Wickett and Brett (4) found a period of maximum stress occurs between 100 and 200 degree-days of development when chum salmon eggs were exposed to oxygen levels less than air saturation. Temporary silting of spawning beds such that oxygen levels were reduced at this period might be expected to be detrimental.

5. Wickett (5) gave 50 cm/hr and 8 ppm as minimum standards of velocity and oxygen content for circulating water in gravel.

In Wickett (6), there are data relating the mean permeability of fenced streams with the mean survival of pink and chum salmon. Output can also be described in terms of fry per sq. yd. of stream bottom. The idea is to present survival in terms of a physical characteristic of the gravel that can be described without relation to grading curves, gravel sampling techniques and their associated difficulties. This appears to be a promising approach.

In Terhune (7), Tables II and IV give a few gravel permeabilities and their grading curves. Mavis and associates (8) (9) give permeabilities for several kinds of sands. Rose (10) developed the laws governing the movement of fluids through porous materials. These data and others like them are useful in considering an action program to develop permeable gravels that will allow a maximum flow of incubating water.

One of the most urgent problems is to specify grading curves for gravels that have the best combination of (a) use by adults; (b) flow of water to incubating eggs; (c) ease of emergence of fry; (d) stability under as wide a range of discharge as possible. Another problem is to develop machines to produce this ideal gravel or gravels in our streams.

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Discussion - abstracted -

References were made to the classifications of silt by various organizations. During the discussion it was indicated that it probably doesn't matter so far as the study of the aquatic environment is concerned which classification is used. The following classification table was furnished by the Soil Conservation Service.

Sediment Grade Scales

Size in Millimeters	Size in Microns	Size in Inches	Class
4000-2000		160-80	Very large boulders
2000-1000		80-40	Large boulders
1000-500		40-20	Medium boulders
500-250		20-10	Small boulders
250-130		10-5	Large cobbles
130-64		5.25	Small cobbles
64-32		2.5-1.3	Very coarse gravel
32-16		1.3-0.6	Coarse gravel
16-8		0.6-0.3	Medium gravel
8-4		0.3-0.16	Fine gravel
4-2		0.16-0.08	Very fine gravel
2.00-1.00	2000-1000		Very coarse sand
1.00-0.50	1000-500		Coarse sand
0.50-0.25	500-250		Medium sand
0.25-0.125	250-125		Fine sand
0.125-0.062	125-62		Very fine sand
0.062-0.031	62-31		Coarse silt
0.031-0.016	31-16		Medium silt
0.016-0.008	16-8		Fine Silt
0.008-0.004	8-4		Very fine silt
0.004-0.0020	4-2		Coarse clay
0.0020-0.0010	2-1		Medium clay
0.0010-0.0005	1-0.5		Fine clay
0.0005-0.0002	0.5-0.24		Very fine clay

How do silt particles in sizes ranging below 2 to 5 mm affect the survival of salmon eggs and young fry? This question was discussed in detail by A. C. Cooper as follows:

All of the major sockeye spawning grounds of the Fraser River system are characterized by a stable flow of clear water over clean gravel with water turbidities far below the limit that can be measured by the Jackson Turbidimeter. This superficial observation alone is considered to be significant evidence of the need for precautionary measures to prevent the introduction of transportable sediments to these streams from artificial sources. A major exception to this condition is found in the pink

demonstrated by data obtained by Pyper in 1954 (Figure 1). The mortalities which occurred are believed to be directly attributable to oxygen deficiency in certain portions of the redd. No detailed internal examination of redds has been made to determine local oxygen deficiencies, but the reduction of dissolved oxygen at various flows is easily demonstrated. The necessary flow to obtain good survival of eggs will therefore depend on the physical character of the material in which the redd is located and in the number and placement of the eggs and alevin within the nest.

Sediments in rivers can be shown to be detrimental to the survival of salmon eggs in redds through lack of oxygen, either by suffocation due to coating of the eggs or by suffocation due to reduction in supply of oxygen bearing water. In extreme situations, the lack of removal of noxious waste products may also contribute to mortality, although we have not attempted to investigate this to date. Wherever in our experimental work, flows of water have been reduced sufficiently to cause nearly complete removal of oxygen from the water by the gravel and eggs, accumulations of decomposing organic materials coat the surface of the water leaving the experimental chamber. The effect of depositions of sediments on the surface of a gravel stream bed is to reduce the flow of water into the bed. This can be demonstrated with a permeater as shown on Figure 2. The results shown on the Figure are not to be considered as generally applicable to all situations and gravels, but they do demonstrate the magnitude of flow reduction which occurs for even minor additions of sediment. The finer sediments, less than 0.3 mm size, were found to be more effective in reducing flow than coarse materials, as would be expected.

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Experiments with this same type of equipment, with sockeye eggs in the gravel have shown that survival of the eggs generally follows the same relationship to flow found by Pyper, although the relationship was not so well defined. Length of exposure to the reduced flow conditions may have bearing on the mortalities incurred, although this was not clearly indicated by this experiment. It is believed that the length of time required to kill eggs at critical levels of D.O. concentration is relatively short, and that the mortalities observed from various lengths of exposure to silt deposition merely reflect a range of minimum flows obtained through the gravel as a result of the silt depositions. While it may not be possible to predict with great accuracy the exact effect of a given amount of deposition of sediment on a stream bed on the survival of eggs in the gravel, the mechanism by which such deposits affect the eggs is simple to understand, if not to measure, and it can be predicted with certainty that survival of the eggs will be lowered.

So far we have been considering only those sediments which are actually deposited in the stream bed. However, examination of the sources of flow of water through stream beds has caused us to examine the possible effects of suspended materials which are too fine to be deposited in the stream bed. During a study of the mechanics of flow through stream beds it was found that the pattern of flow of water

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through the bed depends on the nature of the gravel surface. If the bed is smooth and on an even gradient, flow lines through the gravel will generally be parallel to the bed, with some interchange between the stream and the bed near the surface. If a few large rocks are placed on top of this bed, the flow remains parallel to the surface below about one foot of depth, but interchange at the surface is greatly increased. From these studies it is evident that eggs situated below the hump of a redd are in an excellent position to receive a fresh supply of surface water. It was equally evident, however, that if the water velocities within the gravel, even though they were not deposited on the surface, then it might be expected that such deposition would reduce the flow of water through the gravel and result in coating of eggs with deposits, thereby reducing survival of the eggs.

It can be rationalized that the rate of removal of silt from the water flowing over the gravel will be a function of gravel permeability, the concentration of suspended materials, the velocity of surface flow over the bed, and the topography of the bed. In order to test this relationship a series of experiments have been made, in which a closed circuit of turbid water containing a known constant concentration of sediment finer than 74 microns size was circulated over a gravel bed with surface configurations similar to those shown in the slides. Surface water velocities were varied within the range of the pumps, up to 2 fps and were kept high enough to prevent deposi[illegible] of the sediment on the gravel surface. During the course of the test [illegible] was found to be necessary to continually add sediment to the water [illegible] maintain the constant turbidity and that the rate of addition of sedi[illegible] decreased with time. It was also found that the permeability o[illegible] gravel bed decreased with time, compared to a control bed of gr[illegible] merged in clean water. This is illustrated by the following d[illegible]

Time Minutes	f Addition of Silt Gms/min/sq.ft.	Permeability cm/hr Corrected for change in control
0	.362	1,055,000
580	.217	1,092,000
2995	.109	614,000
5085	.0955	437,000
9130	.0498	229,000

It was also found [illegible] there was a relationship between the variables examined of the for R [illegible] KV^2Z where

R = rate of accu[illegible]ation of silt in gms/min/sq.m
K = permeability in cm/min
V = surface velocity in $\frac{cm/min}{1000}$
Z = a factor depending on surface topography.

It is also known that permeability is a function of the square of a representative particle size, porosity and water viscosity, and also that

through the bed depends on the nature of the gravel surface. If the bed is smooth and on an even gradient, flow lines through the gravel will generally be parallel to the bed, with some interchange between the stream and the bed near the surface. If a few large rocks are placed on top of this bed, the flow remains parallel to the surface below about one foot of depth, but interchange at the surface is greatly increased. From these studies it is evident that eggs situated below the hump of a redd are in an excellent position to receive a fresh supply of surface water. It was equally evident, however, that if the water velocities within the gravel, even though they were not deposited on the surface, then it might be expected that such deposition would reduce the flow of water through the gravel and result in coating of eggs with deposits, thereby reducing survival of the eggs.

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Time Minutes	Rate of Addition of Silt Gms/min/sq.ft.	Permeability cm/hr Corrected for change in control
0	.362	1,055,000
580	.217	1,092,000
2995	.109	614,000
5085	.0955	437,000
9130	.0498	229,000

It was also found that there was a relationship between the variables examined of the for $R = KIV^{n}Z$ where

R = rate of accumulation of silt in gms/min/sq.m
K = permeability in cm/min
V = surface velocity in $\frac{\text{cm/min}}{1000}$
Z = a factor depending on surface topography.

It is also known that permeability is a function of the square of a representative particle size, porosity and water viscosity, and also that

the representative particle size and porosity vary linearly with the amount of fine sediment accumulated in the gravel. Using these relationships it is possible to determine the change in permeability of a gravel of known grading and porosity, which is found to be a function of the product of time and suspended sediment concentration. Thus, for one type of gravel examined, the permeability of the gravel would be reduced 95.7% in 240 days with a suspended sediment concentration of 25 ppm. This same reduction in permeability could have occurred in 24 days with a concentration of 250 ppm. The results of these tests must still be considered very preliminary and analysis of the data on hand is still incomplete, but there is evidence that even small amounts of suspended materials in streams can have a very significant effect on the flow of water through salmon redds and thus on the survival of eggs. The situation actually is not as simple as I have indicated here, since permeability also varies with water temperature, and since in many cases the shape of the gravel surface changes during the egg incubation period, thereby reducing the rate at which any sediments present would be accumulated in the gravel. However, the results obtained to date emphasize the need for clear water if optimum possible survival of eggs is to be obtained.

Sediment Concentration in Streams of the Pacific Northwest - Elliott M. Flaxman

Mr. Flaxman distributed a table (see table following this discussion) showing the results of measurements of concentrations of sediment in streams of the Northwest and a map showing the location of the stations where the measurements were made. The map was generalized and not in such detail as to allow a prediction in any one area that a certain silt load will be produced. It gives a general picture of the contribution of various areas in the Columbia Basin to the sediment load. The table is the result of the combined efforts of a number of State and Federal agencies.

There are several conditions in the Columbia Basin that give rise to high concentrations of silt. Heavier concentrations were during the winter in Western Washington and Oregon where rains are of long duration producing higher flows. There are a few streams in Western Washington that contain glacial rock flows produced in the summer time.

In the eastern portion of the area high concentrations were obtained by the melt of snow cover combined with heavy rains in the spring. Most of the values on the maps are suspended sediment loads. The only total sediment loads are those shown for Southern Idaho where high concentrations result from denuded range lands and placer mining operations. Most of the suspended sediment load will be in the silt sizes.

It was suggested that if the biologist could decide as to the relationship between sediment loads and the aquatic problems, the Soil Conservation Service would be glad to exchange data.

Discussion - abstracted -

The questions regarding samplers and techniques were discussed. The Interagency group studying the problem has developed and standardized samplers. The samples were integrated by lowering the sampler to the bottom and raising it upward through the section. Residue was dried and weighed. The results were reported in the percentage of the dry weight to the total weight of the water mixture.

Total loads were determined by construction of sills across the stream. The turbid flow caused by these sills threw all of the sediment into suspension. The sampler was held just below the lip of the sill.

Several drawings of samplers were shown and discussed. BMH53 sampler developed by the Corps of Engineers for bottom sampling - a hand sampler. The USBM54 is an automatic type sampler also from the Corps of Engineers.

The Corps, Bureau of Reclamation and Soil Conservation Service use a unified soil classification system. The Service is writing a

handbook in which they are recommending the use of the sediment grade scale previously tabulated in these proceedings. These were developed by a Task Force of the American Geophysical Union which was set up for the purpose of standardizing technical classifications.

The following reports published by the Corps of Engineers pertain to the measurement and analysis of suspended sediment. (Supplied by the Geological Survey).

No. 1 - Field Practice and Equipment used in Sampling Suspended Sediment.

No. 2 - Equipment Used for Sampling Bed-Load and Bed Material.

No. 3 - Analytical Study of Methods of Sampling Suspended Sediment.

No. 4 - Methods of Analyzing Sediment Samples

No. 5 - Laboratory Investigation of Suspended Sediment Samplers.

No. 6 - The Design of Improved Types of Suspended Sediment Samplers.

No. 7 - Size Analysis of Suspended Sediment Samples.

No. 8 - Measurement of the Sediment Discharge of Streams.

No. 9 - Density of Sediments Deposited in Reservoirs.

No.10 - Accuracy of Sediment Size Analyses by Bottom Withdrawal Tube Method.

No.11 - The Development and Calibration of the Visual-Accumulation Tube.

No.12 - Some Fundamentals of Particle Size Analysis.

Sediment Concentrations in Streams in the Pacific Northwest

Stream	No. of Samples	Maximum Concen. P.P.M.	Minimum Concen. P.P.M.
Western Oregon			
Tualatin R.	320	390	10
Molalla R.	313	560	T
Pudding R.	330	315	T
S. Yamhill R.	342	800	12
Willamette R. (Salem)	327	400	10
Luciamute R.	342	410	T
Santiam R.	327	503	T
N. Santiam R.	252	250	T
S. Santiam R.	321	370	T
Calapooya R.	323	340	10
Marys R.	339	500	T
Long Tom R. below Fern Ridge Dam	328	279	10
Long Tom R. at Elmira	324	125	7
Coyote Cr.	330	156	16
McKenzie R.	331	240	T
Willamette R. (Springfield)	318	350	T
Coast Fork Willamette R. nr. London	328	400	T
Coast Fork Willamette R. below Cottage Grove Dam	318	260	T
Row R. nr. Star	331	330	T
Row R. below Dorena Dam	108	130	T
Middle Fork Willamette R..	312	380	T
Columbia R. - Vancouver	394	420	T
Columbia R. - Bonneville	58	638	10
Columbia R. - 1948 flood Bonneville	14	1073	57
Illinois R.	15	204	T
S Fk. Coquille R.	15	38,200	2
Ashland Creek	15	2,410	2
Wilson R.	15	295	9
S. Umpqua (Brockway)	15	6,850	T
Calapooya	15	2,930	T
S. Umpqua (Tiller)	15	853	T
N. Umpqua (Glide)	15	2,100	3
Elk Creek (Tiller)	15	450	T
Little R.	15	777	2
Wilson R. (Lee's Bridge)	15	229	4
Flynn Creek nr. Salado	180	83	0
Deer Creek nr. Salado	180	148	0
Needles Branch nr. Salado	180	92	0
Western Washington			
Green R.	162	1,900	0
Chehalis R.	15	164	3
Skookumchuck (Bucoda)	15	98	2
Cowlitz	15	112	27

1/ Maximum daily

2/ Includes measurement of bedload as well as suspended load.

(continuation - Western Washington) Stream	No. of Samples	Maximum Concen. P.P.M.	Minimum Concen. P.P.M.
E. Fork Lewis R.	15	102	4
Skookumchuck (Tenino)	15	88	1
S. Fork Newaukum (Forest)	15	195	13
S. Fork Newaukum (Alpha)	15	71	T
N. Fork Newaukum (Water Intake)	15	65	T
N Newaukum (Forest)	15	304	T
White R. below Emmons Glacier nr. Enumclaw	9	15,500	520
Eastern Oregon			
Bully Creek nr. Vale	200	1,780	11
Crooked R. nr. Prineville		1,180	7
Umatilla R. nr. Hermiston	87	4,540	10
Umatilla R. at Pendleton	18	6,500	T
Eastern Washington			
Columbia R. at Pasco		680	T
Snake R. at Central Ferry		935	23
Walla Walla R. nr. Touchet	36	46,000	T
Touchet R. nr Touchet	31	82,000	T
Yakima R. nr. Richland		808	6
S. Fork Palouse R.	2,000	9,000 1/	T
Four Mile Creek	2,000	13,600 1/	T
Missouri Flat Creek	2,000	5,000 1/	T
Southern Idaho			
Boise R. nr. Twin Springs	525	590	T
Boise R. at Notus	"	1,610	T
Boise R. at Dowling Ranch 2/	"	235	T
Cottonwood Creek nr. Arrowrock res. 2/	"	18,700	T
Grouse Creek 2/	"	93,600	T
Moore Cr. above Granite Creek nr. Idaho City	"	2,900	T
Moore Creek above Thorn Creek	"	4,390	T
Granite Creek nr. Idaho City 2/	"	21,200	T
Bannock Creek nr. Idaho City 2/	"	10,900	T
Pine Creek nr. Idaho City 2/	525	4,220	0
Pine Creek above Barry Placer Diver 2/	"	85,000	T
Elk Creek nr. Idaho City 2/	"	56,300	T
Elk Creek above Cold Hill placer diversion 2/	"	1,840	T
Cottonwood Gulch 2/	"	42,000	T
New York Canal 2/	"	3,720	T
Northern Idaho			
Kootenai R. at Leonia Bridge	141	810	T
British Columbia			
Kootenai R. at Newgate	182	885	T
Montana			
Clark Fork at Plains	175	237	T

Watershed Management - Grazing, Deforestation and Road Building -
William Bullard

This discussion deals largely with the sources of siltation and what can be done about it. Grazing, deforestation and road building do not need to have the deleterious effects it so often has. With carefully managed operations we can avoid most of the soil disturbance which causes the trouble.

Mr. Bullard presented the following outline of factors to consider in watershed management to the end of controlling erosion and subsequent siltation of streams.

I. Causes and Sources of Siltation

A. Natural

1. Glacial "flour"
2. Avalanches and landslides
3. Soil creep and slump, rock weathering and talus
4. Channel degradation
5. Channel aggradation and barkcutting
6. Fire and subsequent erosion
7. Grinding of stream debris loads during high flows
8. Reduction of cover density and soil disturbance by big game concentrations
9. Natural debris jams in channels

B. Man-caused

1. Soil-disturbing operations on watersheds

a. Timber harvest
b. Road and other construction
c. Right-of-way clearing
d. Grazing by domestic stock
e. Cultivation of soil for crops
f. Recreation concentration
g. Mining
h. Fire and subsequent erosion

2. Channel-disturbing operations

a. Timber harvest
b. Road construction
c. Grazing domestic stock
d. Mining
e. Dam and diversion construction

3. Runoff - concentrating operation

   a. Some timber harvest methods
   b. Road and trail construction and drainage
   c. Urbanization - impervious roofs and pavement

II. Correction of Causes of Siltation

A. Manage Operations to Avoid Hazards

1. Timber harvest

   a. Layout of cutting areas
   b. Direction of log removal-yarding methods
   c. Restrictions on equipment - type and use

2. Grazing (in terms of cover density and soil conditions)

   a. Big game management
   b. Control of grazing by domestic stock

3. Mining

   a. Control of tailings
   b. Control of dredging

4. Agriculture (conservation farming, improved cultural methods)

   a. Contour strip cultivation
   b. Grassed drainage ways
   c. Cover crops
   d. Efficient irrigation

5. Road construction

   a. Location and design
   b. Construction methods
   c. Drainage disposal
   d. Slope stabilization
   e. Surfacing

III. Rehabilitation of Sources of Siltation

A. On Watershed Slopes

1. Improvement of cover density and soil stabilization

   a. Tree-planting and grass-seeding
   b. Control of grazing
   c. Control of fire

2. Control of runoff and erosion

a. Terracing
b. Contour furrowing and trenching
c. Gully plugs
d. Drainage diversion and sediment settling
e. Conservation farming

B. In Channels

1. Bank protection works
2. Clearing jams of floatable debris
3. Fills to stabilize channel bottoms
4. Debris basins

IV. Current Programs to Control Siltation

A. Federal and State Agency Programs

1. Education and information

a. Hazards of land abuse
b. Prescriptions for proper methods of land use

2. Control of operations by land-managing agencies

3. Stipulations

a. Operating contracts
b. Easements and rights-of-way
c. Licenses and permits

3. Rehabilitation projects

4. Soil bank and conservation reserve

B. Cooperative Programs

1. Self-regulation by private agencies

2. Education and information

a. Society of American Foresters
b. Northwest Pollution Control Council
c. Northwest Forest Soils Council
d. Soil conservation districts
e. Sportsmen and conservation associations

C. Legislation (primarily State and County)

1. Public Health Codes
2. Forestry Codes
3. Fish and Game Codes
4. Dredge-mining Codes

Overgrazing is one of the factors in causing siltation. Cover is removed and the soil compacted. Rain and snow-melt cannot penetrate the soil and runoff is increased causing erosion. Usually the best soil is removed and ends up in river bottom lands or in stream beds. This soil should be kept in the uplands and forests.

There are several methods of control of erosion including: refusal to graze or log on wet and soggy soils; use care in the layout of cutting areas and access roads; do not work close to channels or live streams; select type of equipment; train the operators; and rehabilitate the disturbed areas.

Road construction is one of the most significant operations as regards siltation. There is too long a lapse between construction and stabilization. The disposal of cut material should not be made in the vicinity of a stream. This material can be the source of siltation for many years.

Discussion - abstracted -

Does the Forest Service vary regulations with area? Yes, the management varies with soil types terrain and other factors.

Who makes the regulations? The Service has general policies, but the ranger who lays out the timber sale will develop the regulations to fit the area.

Are regulations adequate to control siltation? Not always. There is still the need for research, although experience has shown certain practices to be adequate.

Due to heavy erosion in the past, certain areas have reached a point of stabilization in which even rapid runoff does not cause excessive erosion.

Is it practical to leave a strip of trees along a stream as a protection against siltation and to provide shade for aquatic life? The answer will depend on local conditions as will the depth of the strip. It is practical, but the policy should be flexible.

If we are to have the best multiple use plan for land and water we must use a united approach in which all agencies participate. Forest

rangers and road builders are not always aware of the problems and effects. The biologists should work with them.

(Mention was made of a meeting of the Washington Association of Fish and Game Commissioners to be held in Portland the last week in June. The purpose of this meeting is to develop a uniform code for fishery habitat control. Eleven western states are working on this code. It will involve forest management, highway construction, and all other operations influencing land erosion).

Mining and Dredging Wastes - Forest Hauck

This subject of the effect of mining and dredging wastes on the aquatic habitat is a controversial subject. However, there are ways of coming to a common point of agreement between opposite points of view. The State of Idaho has some of the largest wilderness areas in the nation. The silt loads to streams in these areas are small for the most part except where industry has moved in and caused damage. Four years ago, the Federated sports clubs introduced an initiative which resulted in the adoption of a dredge mining waste law. This carried by a large majority.

We have four general sources of mining wastes, namely:

1. The pulverized rock which result from grinding in various types of mills and which vary in size from large rocks to substances which will pass a 1000 mesh screen. They are usually carried away from the mill in water together with other substances used to separate the mineral from the rock. Since most of the mines are located in mountainous country, the natural place to deposit them is in the stream bed.

2. The waste ores themselves which escape the milling process or which have no value. These make their way to the stream.

3. Mine waters which may be pumped or which run from the mine to the stream. These carry chemicals from the lodes.

4. The chemicals which are added in the milling process to separate the minerals from the rock.

As methods are improved for milling, the siltation problems increase. Mill tailings are becoming finer and are carried much further downstream than formerly. Lower grade ores are being handled and consequently greater quantities of rock are processed adding to the siltation problem.

New chemicals and disintegrating agents add to the hazard downstream. Frothing agents produce toxic conditions in the stream.

The substances deposited in the streams are so fine they feel like slimy material. The high turbidity cuts down the light and interferes with photosynthesis. Silt loads are carried farther downstream each year by freshets which pick up the deposited material and move it down to a new location.

Many of the salts of the heavy metals are toxic. For example, lead and zinc sulfide. Some other salts undergo chemical changes and become soluble in which form they may be toxic.

Just after World War I a litigation occurred between agricultural and mining interests in the Coeur d'Alene. The mines on the south fork were sued. They alleged that the chemicals were poisoning the soil and cattle and horses were killed. The mining companies then acquired most of the farm lands and used them for the dispersal of the wastes to keep the material out of the streams.

More recently the Game Commission has had losses of wild life, especially duck and swan in the same area. Evidence indicate lead as the cause.

In some cases chemicals used combine to form toxic substances. An example is the cobalt mines on the headwaters of the Salmon River. Here ferric salts and sulphuric acid combine with the effluent from ponds used to settle tailings causing a precipitation of iron oxide on the stream bed for a distance of 45 to 50 miles. The problem was solved by adding lime to the waste and settling the iron in a pond.

Dredge mining is nothing but a large placer operation. Equipment is usually located on a floating barge. The material is taken from the stream and returns the unwanted solids to the stream bed. As a result of the new dredging legislation in Idaho, the operator is required to smooth the stream bed, replant the area and put the stream back in as near its natural condition as possible. Water used must be returned to the stream in a reasonably clear condition.

Dredge mining removes the fines from the soil making it more porous. This results in erosion during the spring runoff. The amount of silt from a dredging is very high and continues for years after the operation has ceased. Not only does it affect fish life, but it interferes with other water uses such as irrigation and fills reservoirs and canals.

Eggs and fry are found in certain Idaho streams every month of the year. Winter operation of dredges are, therefore, just as damaging as those at other periods.

Experiments conducted with dredge mining wastes showed that in every case the mortality of eggs, fry and fingerlings was greater in silt ladened water than in clear water. The silt used in these tests was taken from a pond in which tailings were settled and the concentrations used were the same as occurred in the stream one mile below the dredge under study.

Reference was made to a study by Dr. Ellis on Coeur d'Alene Lake.

Sand and Gravel Operations - Richard Wagner

There are several methods by which gravel is removed from a stream bed. These consist of a drag line and bucket which moves up and down the stream over the gravel area, the clam shovel which is more stationary, and the scoop-mobile which is moved in during low water to remove a bar of gravel.

The Washington Pollution Control Commission require the ponding of gravel washings before discharge. Tests are made above and below an operation using the Jackson turbidimeter but since this measurement depends on light transmission, the results did not establish the problem. Variations in the size, shape and type of particle exhibit different effects and the results are not quantitative. Quantitative measurements by actually weighing the material do not tell the story. So we decided to measure the deposition on the bottom and the effect on fish food organisms, primary insects, clams, snails, etc. This proved to be a more effective measure for persuading operators of pits that their operations were damaging the stream.

It is one matter to control an established operation and another to control fly-by-night gravel removal. The latter are commonly associated with highway construction. The removal and washing of the gravel for the highway operates during the construction of a certain stretch of road and then moves on when the contract is finished.

A source of siltation in connection with gravel removal is the disposal of the top soil. This may be pushed into a stream bed or piled next to the pit. The material is soft and subject to excessive erosion even with minor runoff.

Silt settles in pockets and pools in the stream bed. In the smaller tributaries these are resting areas for smaller fish.

Tests were made to determine the effect of the organic constituents in the silt load. It was found that the oxygen demand was great. Oxygen concentrations decreased to low levels in a few cases.

A study of bottom deposits showed that the material below the surface in some cases was anaerobic and the substances leaching from the deposits were extremely toxic. These properties may be due to the reduction of such compounds as arsenates which may increase the toxicity.

In October, 1957, the Washington Pollution Control Commission made an investigation of turbidity and siltation of the Wynooche River in Western Washington. The source of the turbidity and silt was a gravel removal industry - drag line operation. Objectives of the study were:

a. To determine: (1) the normal suspended solids and turbidity

of the river water, (2) the suspended solids and turbidity of the river water when influenced by the gravel operation.

b. To determine by bio-indices, the effects of the introduced sedimentation on the aquatic insect population.

c. To determine the effects of the induced siltation upon the habitat utilized by juvenile salmonoid fishes.

This is a permanent gravel operation with fixed equipment. Part of the draglining takes place in the river channel but over a number of years there has been enough draglining to produce a sort of core off to one side of the main channel. A dyke has been constructed at the lower end of the core to help to keep the turbid water from being transported direct to the river.

Analyses of the water were made for suspended solids, dissolved oxygen, and turbidity and hydrogen ion concentration. Samples for aquatic insects were collected by means of a square foot bottom sampler.

Very briefly, the results are as follows:

Normal turbidity upstream indicated that the water was clear and the bottom free from silt. Immediately downstream the turbidity ranged from 91 ppm and 102 ppm of suspended solids. The introduced sedimentation caused a marked reduction in the aquatic insect population. Quantitative analyses of bottom samples showed population reduction 75 to 85 percent below the gravel operation. The reduced insect population in the silt deposited in the gravel has created a condition which has eliminated two basic needs (food and cover) for young trout and salmon. This, in turn, will reduce survival rates of these fishes. Although the silt deposits in this area below the operation and the turbidity values were lower than some accepted standards elsewhere in the country, they still appear to be too high for reasons given above. Tests showed, however, that where draging was restricted to the cove area behind the dyke, turbidity and silt were not so harmful as where the draglining was taking place in the main channel.

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